Fabrication of Division-of-focal-plane Polarizer Arrays by Electron Beam Lithography

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Abstract—The division-of-focal-plane (DoFP) polarizer is used to capture polarization information in real time without rotating the polarizer. In this paper, different periods of aluminum nano-wire grids with four different orientations offset by 45° are fabricated using electron beam lithography (EBL) and inductively coupled plasma-reactive ion etching (ICP-RIE). The pitch of each unit is $7.4\ \mu\text{m}$ with a standard square. The transmission intensity measurement of DoFP arrays was presented to obtain the extinction ratios and transmission ratios which were used to evaluate the performance of grid polarizers.

Keywords—Division-of-focal-plane; nano-wire grid; EBL; polarizer

I. INTRODUCTION

Nature light contains the information of intensity, wavelength and polarization, the light reflected by object is polarized, so that the polarization information can help us to gain extra useful information, but human eyes are blind to it [1]. Polarizers can get the polarization information and get the polarization images by camera. Among the polarizers, metallic nano-wire polarizers are extensively used with the advantage of high extinction ratio [2]. When unpolarized light is incident onto the metal nano-wire gratings, the transverse electric (TE) wave is mostly reflected by the metal gratings, and the transverse-magnetic (TM) wave is mostly transmitted [3,4,5]. The ratio of transmitted TM and TE is the extinction ratio. Traditional polarization imaging works based on the division of time [6,7] which changes the filter to capture images in different times, and the division of amplitude that the image is split into multiple paths. Each path has its own polarization optics and image plane [8,9]. The division of focal plane is a new method which is widely used in decades, and the schematic of DoFP polarizer arrays is shown in Fig. 1. DoFP sensors include imaging elements and nanowire polarization filters on the same substrate. The advantages of DoFP polarization sensors are compact and stabile, and it can capture all polarization information with an image in real time [10-16]. Numerous of approaches to the fabrication of DoFP metallic polarizer arrays have been proposed, such as laser interference lithography, nanoimprinting lithography [17,18] and electron beam lithography [19,20]. However, laser interference lithography and nanoimprinting lithography are complex for four direction gratings. Electron beam lithography has a high resolution and a simple process, compared with other technologies.

Fig. 1. Schematic of DoFP polarizer arrays.

In this paper, we focus on the fabrication of DoFP wire-grid polarizer arrays with the periods of 200nm and 170nm by EBL and ICP-RIE, which are used in polarization detection. Metal aluminum is used to fabricate the polarizers which has the best performance in the visible light [21]. The period of the grating should be smaller than the incident wavelength, so that the grating has only the zero-order diffraction wave [22]. The extinction ratios and transmission ratios of different periods were calculated in red wave band.

II. METHOD AND FABRICATION

A. Fabrication Process

The fabrication of DoFP polarizer arrays is carried out with EBL and ICP-RIE. The metal is aluminum and the periods are 200nm and 170nm. The line widths are 100nm. The aluminum nano-wire grid with four different directions are 0° , 45° , 90° and 135° . The pitch of each unit is $7.4\ \mu\text{m}$ with $1\ \mu\text{m}$ interval to reduce the cross talk between adjacent units. The fabrication process of DoFP polarizer arrays is shown in Fig. 2. and described as follows:

Fig. 2. Fabrication process of DoFP polarizer arrays. (a) Quartz glass substrate; (b) Aluminum is deposited on the substrate; (c) electric beam photoresist is spin coated on the surface of aluminum; (d) The designed patterns are exposed on the photoresist; (e) ICP-RIE; (f) The remaining photoresist is removed.

(1) A High transmittance quartz glass slide is used as the substrate of the DoFP polarizer. The quartz glass is cleaned by ultrasonic cleaning machine with deionized water, acetone and anhydrous alcohol, and dried by nitrogen.

(2) The glass substrate is coated with 150nm aluminum layer, and the coating is compact and uniform.

(3) A 150nm layer of positive electrobeam photoresist (AR-P 6200) is spin coated on the surface of aluminum at 4000rpm for 60s, and post baked at 180°C for 90s

(4) The DoFP patterns designed by CAD are exposed with electron beam lithography in the scanning electron microscope (FEI QUANTA FEG 250). The voltage is set as 30kV, and the spot is set as 2. After the exposure, the sample is developed using developing liquid for 60s, and washed using deionized water for 30s.

(5) Inductively coupled plasma-reactive ion etching (ICP-RIE) (SENTECH SI500) is used to transfer the developed patterns to the aluminum layer with Cl_2 and BCl_3 as the etching gasses to etch Al and Al_2O_3 for 80s.

(6) The remaining photoresist is removed by dispersator.

B. Fabrication Result

After the technological process listed in II.A, the fabricated DoFP polarizer arrays are observed by SEM, as shown in Fig. 3. Fig. 3(a) and Fig. 3(b) show the wire grids with four directions and the period is 200nm. Fig. 3(b) shows the details of Fig. 3(a). Fig. 3(c) shows the wire grids with the period of 170nm.

(a)

(b)

(c)

Fig. 3. Fabrication result of DoFP polarizer arrays observed by SEM. (a) and (b) The grids with the period of 200nm; (c) The grids with the period of 170nm.

A. Measurement Setup

Fig. 4. Measurement setup for the measurement of DoFP polarizer arrays.

The measurement setup is shown in Fig. 4. The array of LEDs is used as the source to irradiate into a 4" integrating sphere to provide the uniform light intensity, and a narrow band filter (CWL=630, FWHM=10) is used to get a single wavelength source. The polarization angle of incident light is varied from 0° to 180° with an increment step of 5° via an electric turntable controlled by a motor. The sample is put on the XY move stage and imaged with a CCD imaging sensor [23]. Fig. 5. show the CCD images of 200nm period grids with the orientations at 0° , 45° , 90° and 135° .

 Fig. 5. The images are captured by CCD with four orientations (a) 0° polarized light; (b) 45° polarized light; (c) 90° polarized light; (d) 135° polarized light.

The DoFP polarizer array is measured to obtain the extinction ratio and the maximum and minimum transmission intensity responses. The extinction ratio is calculated by Eq. 1.[24]

$$\text{Extinction Ratio} = \frac{I_{\max}}{I_{\min}} \quad (1)$$

where $I_{\max}$ is the maximum transmission intensity response that the grid direction is parallel to the direction of fabricated arrays. $I_{\min}$ is the minimum transmission intensity response that the grid direction is vertical to the direction of fabricated arrays.

B. Measured Transmission Intensity

The transmission intensity responses of four direction polarizer arrays are shown in Fig. 6. The transmission intensity distributions follow the Malus's law. The extinction ratio of 200nm and 170nm period gratings are 8.97 and 38.99. The maximum and the minimum polarization transmittances of 200nm period are 65.63%, 7.31%. The maximum and the minimum polarization transmittances of 170nm period are 76.75%, 1.97%. The difference between different directions transmission intensity responses are due to the fabrication result difference of each orientation.

(a)

(b)

Fig. 6. Transmission intensity curves. (a) Period of 200nm; (b) Period of 170nm.

IV. CONCLUSION

In this paper, DoFP polarizer arrays with different periods are fabricated by EBL and ICP-RIE. The transmitted images of DoFP polarizer arrays are captured by a measurement setup, the responses of transmission intensities, extinction ratio and transmission ratio are obtained and calculated. The experiment results indicate that the period of nano-wire gratings will affect the performance of DoFP polarizers.

ACKNOWLEDGMENT

This work was supported by the “111” Project of China (D17017), National Key Basic Research Program of China (973 Program No.2012CB326406), EU FP7 (BioRA No.612641), China-EU H2020 (FabSurfWAR Nos.2016YFE0112100 and 644971), EU H2020 (MNR4SCell No.734174), National Natural Science Foundation Program of China (Nos.61176002, 11103047 and 11504030), and Jilin Provincial Science and Technology Program (Nos.20160520101JH, 20160101318JC and 20160623002TC).

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